RISK AND DECISION METHODS APPLIED TO AQUATIC ECOSYSTEM MANAGEMENT

Considerations for Invasive and Endangered Species

B.S. PAYNE, A.C. MILLER, B. SUEDEL
U.S. Army Engineer Research and Development Center
Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199 USA

Abstract

Increased global trade and modern intercontinental transportation have made invasive species an increasingly prominent stressor of freshwater ecosystems. Invasive species risk assessments, which range from simple screening protocols that focus on species attributes and ecological requirements to rigorous analyses of infestation, have become an important component of environmental impact assessment. In this paper we present two recent case studies in which risk and decision methods were applied to non-toxicological environmental issues that are central to many aquatic ecosystem management programs. The first example reviews potential infestation by the zebra mussel, *Dreissena polymorpha*, on Bayou Bartholomew, located in southeast Arkansas, as a result of the proposed augmentation of low flow conditions by pumping water from the nearby and much larger Arkansas River. The second example presents a retrospective analysis of the results of transplanting fat pocketbook pearly mussels, *Potamilus capax,* from an approximately 6-km reach of a drainage ditch in eastern Arkansas. The two examples presented herein indicate the potential for improving environmental decision-making in the face of uncertainty—but in the presence of substantial information. As more rigorous attempts are made to widen and enhance applications of risk and decision methods to environmental decision-making, ecosystem management is likely to further improve.

1. Introduction

Contaminant and human health issues have been at the forefront of environmental applications of risk and decision methods. Toxicological risks were certainly the initial focus of risk assessment protocols developed in the United States [39; 54]. However, risk and decision methods have wider applicability to environmental assessment and impact analysis. Risk analysis methods are being modified to address invasive species issues (e.g., [50; 53]). Formal decision methods had their

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origins in business and legal practice [12] and now are emerging in environmental management-oriented decisions [29].

The second half of the 20th century brought expansive development of information and knowledge of the biology and ecology of populations and communities in major ecosystems. While uncertainty still exists in ecology, lack of information and knowledge cannot be allowed to paralyze ecosystem restoration and management decisions. Integration of information, application of moderately comprehensive ecological models, risk analysis, and formal decision methods all offer ways to meet environmental assessment and ecosystem management needs in the face of uncertainty.

In this paper we summarize two recent examples in which risk and decision methods were applied to non-toxicological environmental issues that are central to many aquatic ecosystem management programs. The first example deals with application of risk analysis to an invasive species dispersal concern (see also [43]). The second deals with a retrospective analysis of a set of endangered species management decisions [38], showing how the use of specific decision tools can improve the decision-making process.

2. Example 1: Infestation Potential of an Invasive Species

2.1. BACKGROUND

Invasive species and habitat degradation generally are accepted as leading threats to biodiversity [13; 30; 45]. Nearly all aquatic ecosystem management programs include a component that addresses invasive species. Freshwater aquatic habitats are the most imperiled ecosystem on the planet, due to use of freshwater ecosystems for industrial and human waste removal and processing, irrigation, flood control, power generation, transportation, and drinking water. In the medium and large rivers in the United States, habitat impacts are due to dams, locks, straightened river channels, dredged navigation channels, levees, dikes, and training structures occurred with initial construction of the inland navigation and flood control system. Habitat degradation is also associated with pollution and degraded water quality, although much of this loss has been remedied or ameliorated since regulatory implementation of clean water legislation.

Increased global trade and modern intercontinental transportation have made invasive species an increasingly prominent stressor of freshwater ecosystems [30]. Invasive species risk assessments have become an important component of environmental impact assessment. These assessments range from simple screening protocols that focus on species attributes and vectors of dispersal with largely narrative presentations of species biology and ecological requirements to rigorous predictions of infestation risk.

Dispersal likelihood and the physiological and ecological requirements of a species largely determine infestation potential in a particular region. Despite dispersal, infestation level may stay low due if the species is living in only marginally suitable habitat. Conversely, invasive species tend to thrive in more suitable habitats, as predators, competitors, pathogens, and other natural control mechanisms are often lacking.

Our example focuses on how physiological and ecological preferences of a species can be used in relation to habitat characteristics to support qualitative and quantitative risk assessments. We address potential infestation by the economically and ecologically important zebra mussel, *Dreissena polymorpha*, of a small river, Bayou Bartholomew, in southeast Arkansas due to proposed augmentation of low flow by pumping of water from the nearby and much larger Arkansas River (Figure 1). This particular example demonstrates how available information on habitat conditions and species physiological ecology can be combined to assess infestation risks in a fashion that is easily communicated to various stakeholders and managers.

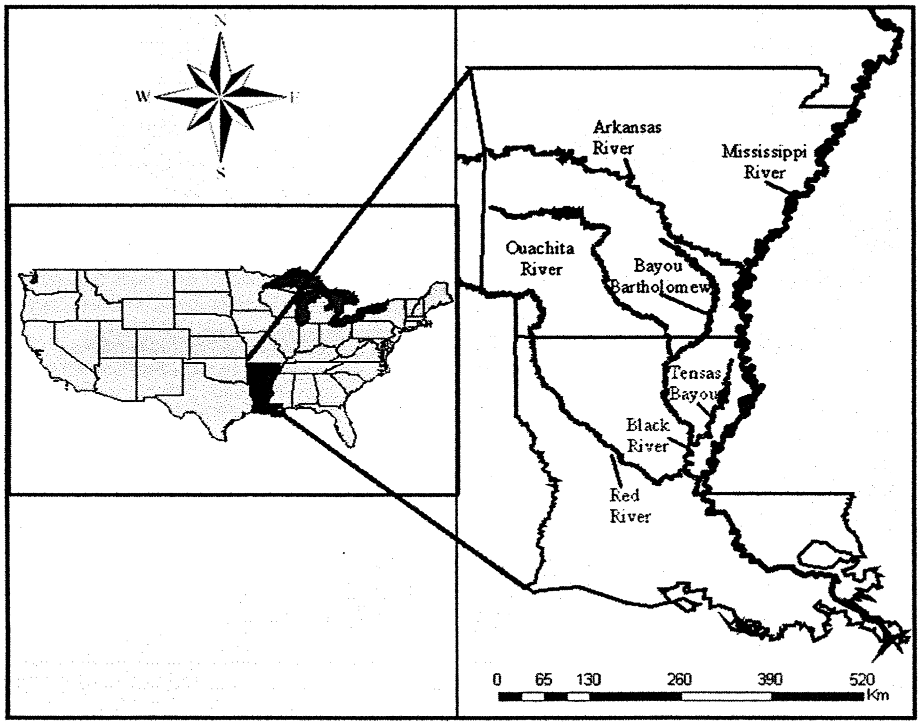

Figure 1: Map showing the locations and spatial proximity of the Arkansas River to Bayou Bartholomew and the Ouachita River.

The zebra mussel is a small freshwater bivalve native to the region of Europe surrounding the Black, Caspian, and Aral seas (see [47] and [51] for summaries of this species invasive history). Zebra mussels spread throughout much of Europe as canals, waterways, and boat traffic provided routes of dispersal that did not exist much before the Industrial Age. The zebra mussel was spread to the North American Great Lakes by ballast water exchange. This species was found in Lake St. Clair in the mid 1980s and, within a few years, spread throughout much of the inland navigation system of the United States east of the Continental Divide. Zebra mussels now occur throughout the Mississippi River from its upper reaches to the lowermost river near New Orleans, Louisiana. However, high water temperatures in summer generally prevent the relatively cool water species from thriving in the southern United States [2; 3].

2.2. PREDICTING EXPOSURE TO INVASIVE SPECIES

It is useful at first to broadly discuss a basic approach to evaluating invasive species infestation risks. Figure 2 provides an overview of the basic risk assessment protocol, tailored to invasive species. With respect to the protocol depicted in Figure 2, it is important to note that herein we deal predominately with methods of predicting exposure to invasive species. We do not address biophysical and socioeconomic effects.

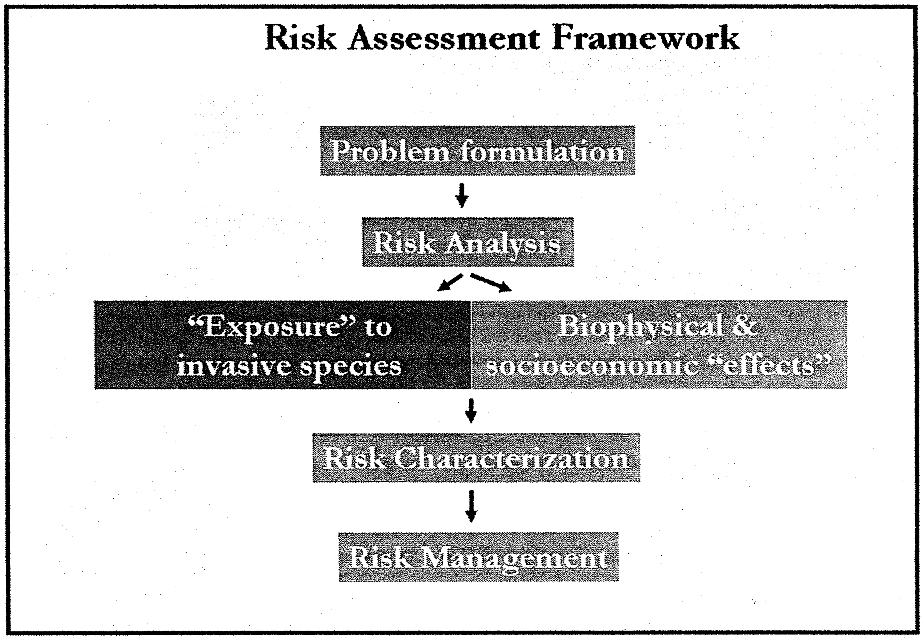

Figure 2: A simple diagrammatic representation of the risk assessment framework for invasive species; adapted from Suedel et al. 2006.

Infestation risks for most invasive species are determined by the interplay of habitat conditions and physiological tolerances. Thus, rapid and thorough compilation and analysis of existing information on the invasive species of interest is always an important early step. Different project settings and environmental concerns merit different levels of scrutiny. Thus, it is appropriate to consider risk assessment approaches that range in difficulty and cost. Experience suggests approximately three levels of risk assessment, from the least demanding to most demanding. All are based on the physiological ecology of the invasive species.

1. Level 1

   At the lowest level, useful risk guidance can be as simple as a table of habitat conditions versus tolerances of those conditions. More specifically, categories of infestation potential (e.g., low, moderate, and high) associated with a range of values for each of several critical habitat parameters. Such tables have been developed independently for a number of important invasives, or could be derived from reviews of species physiological ecology that are not aimed at a simple tabular summary. For example, Claudi and Mackie [11] did just that by compiling a simple table to guide infestation risk analysis of the zebra mussel in North America.

2. Level 2

   A higher level of detail and certainty would invoke the logic if not the accounting framework of the "habitat suitability modeling" approach developed by the U.S. Fish and Wildlife Service in the 1980s. In this approach, an attempt is made to correlate infestation potential with known habitat conditions (e.g., [26; 51]). Habitat conditions might be known from existing information, require field measurements, or some combination of both. This approach is based on organismal physiological tolerances and applied to a quantitative analysis of habitat and water quality conditions.

3. Level 3

   Ultimately, interplay habitat and organismal preferences (and potentially other factors) results in distributional patterns that are amenable to statistical analysis and can be used to build empirical models. Rigorous statistical models can be developed that allow quantification of uncertainty (e.g., [46]). A conceptually similar and rigorous approach is embodied in recent attempts to apply methods from informatics. In this approach, rule-based models of infestation potential are derived from extensive data sets on species-habitat relationships in species' native ranges [44].

All of these levels of analysis, and especially the first two, derive mostly from existing information. The final level requires paired observations of abundance and habitat conditions, usually from the invasive species home range but potential from a newly infested region. Such data sets are less certain to be available and more demanding to evaluate.

Once an invasive species has accomplished intercontinental or other wide-reaching dispersal, considerable attention is typically devoted to predicting infestation likelihood for regions and sites in reasonable proximity to those aquatic ecosystems initially infested by the recent invader. In the following paragraphs we demonstrate the use of existing habitat and tolerance data to perform an intermediate level analysis for such a prediction.

2.3. A PROPOSED INTER-BASIN WATER TRANSFER PROJECT

The inter-basin transfer of interest involves proposed pumping of water from a large river, the Arkansas River, to the headwater reach of a small river, Bayou Bartholomew, in southeast part of the State of Arkansas (Figure 1). This proposed pumping project created concern because the Arkansas River supports a zebra mussel population (although the population is seasonally suppressed in summer by high water temperature [4]). Bayou Bartholomew does not presently support zebra mussels, and the Bayou drains into the larger Ouachita River which supports many species of native unionid mussels that would be potentially harmed by zebra mussel infestations. Our purpose herein is not to analyze the project, but rather to demonstrate how information on habitat conditions and species physiological ecology can be combined to assess infestation risks in a fashion that is easily communicated to various stakeholders and managers.

2.4. THE INFESTATION RISK ANALYSIS

In brief overview, we approached the problem by: reviewing extensive published literature on the physiological ecology of *Dreissena polymorpha*, with emphasis on habitat requirements especially as they relate to the southerly distribution of this species in North America. Next we characterized the habitats in the Arkansas River, Bayou Bartholomew, and the Ouachita River with respect to critical parameters identified from the literature review. These variables included water temperature, pH, calcium, and dissolved oxygen – all of which were potentially limiting to zebra mussels in the river system under investigation. Our purpose here is not to provide a comprehensive analysis of this information (see [11] and references within), but rather to demonstrate with clear examples, how knowledge of zebra mussel physiological ecology efficiently supported risk analysis.

Habitat suitability curves for the four water quality parameters are presented in Figure 3. These are essentially similar to curves used in a prior analysis of zebra mussel infestation risk in the State of Florida [26] that, in turn, and are based mostly on published information on zebra mussel physiological ecology (e.g., [11; 47]. We do not attempt a through review of such information herein; our point is more simply that such knowledge of physiological ecology typically can be compiled for invasive species of greatest ecological and economic concern. Basic aspects of organism-habitat relationships are reasonably well known for such species, or become the focus of early investigations of pest species invasions.

Existing measurements of water quality were compiled from various source and sites and summarized in a series of figures (e.g., Figure 4). For monitored sites throughout Southeast Arkansas we compiled composite scores of habitat suitability, using a simple weighted average of habitat suitability with respect to pH, calcium, temperature, and dissolved oxygen. We included this simple regional analysis because, ultimately, concern will exist for not only Bayou Bartholomew but other stream systems in the same region.

For the three rivers of initial interest, the Arkansas River, Bayou Bartholomew, and the Ouachita River, a simple plot of pH provides the essence of our risk analysis (Figure 5). More specifically, only the Arkansas River has a pH that will generally

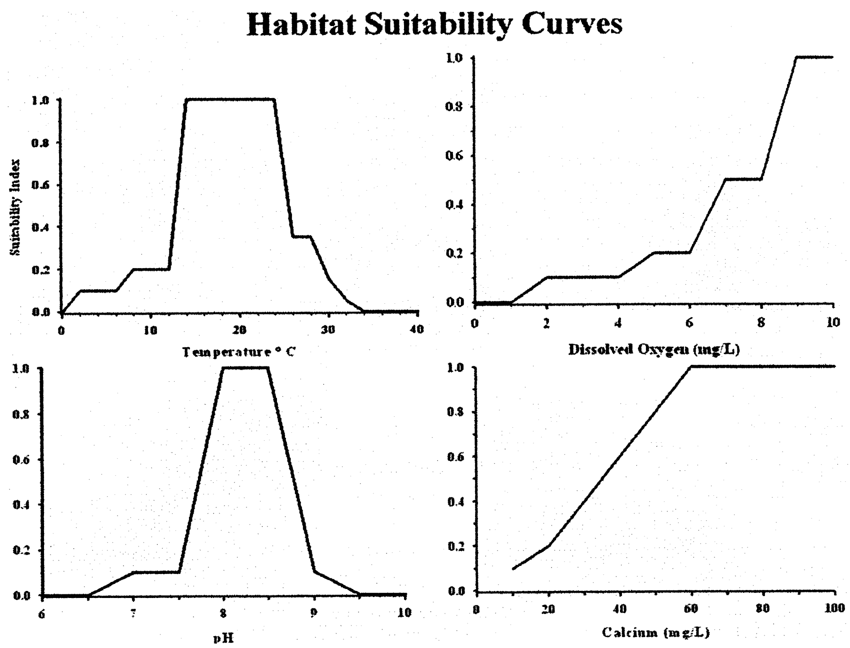

Figure 3: Habitat suitability curves showing zebra mussel preferences with respect to four often limiting water quality variables: temperature, dissolved oxygen, pH, and calcium.

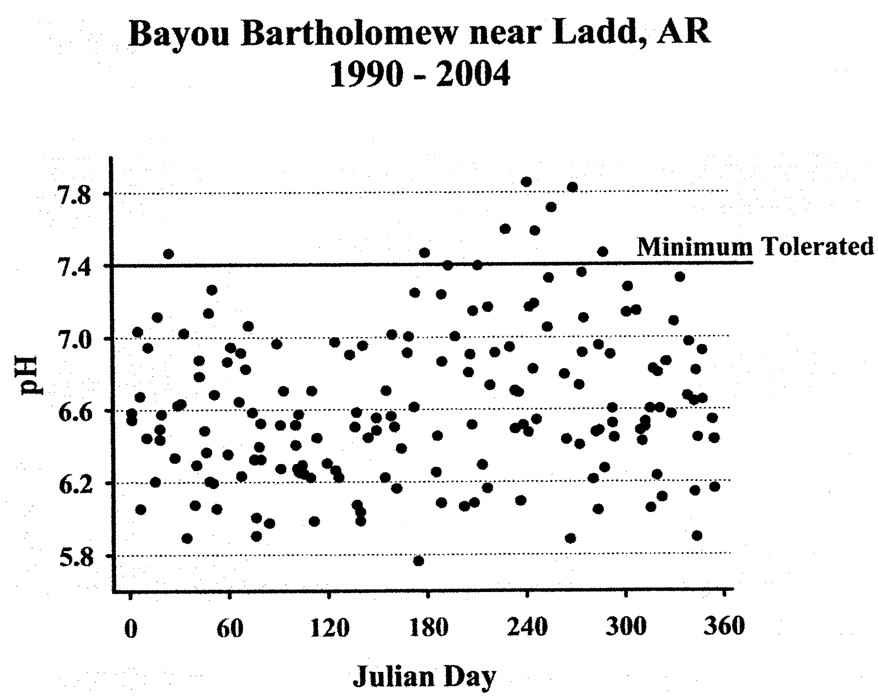

Figure 4: Example of compiled water quality data at a single site in Bayou Bartholomew compared to the minimal requirements of zebra mussel larvae.

support zebra mussels. Zebra mussels are particularly susceptible to acidic or even slightly alkaline water. During their larval stage, when their calcareous shell is first being formed, they require a pH of 7.4 or greater to survive [33]. This condition is met only in the Arkansas River. The risk of successful infestation of Bayou Bartholomew is low – only sporadically does pH equal or exceed a value of 7.4. Conditions are even more limiting in the slightly more acidic Ouachita River.

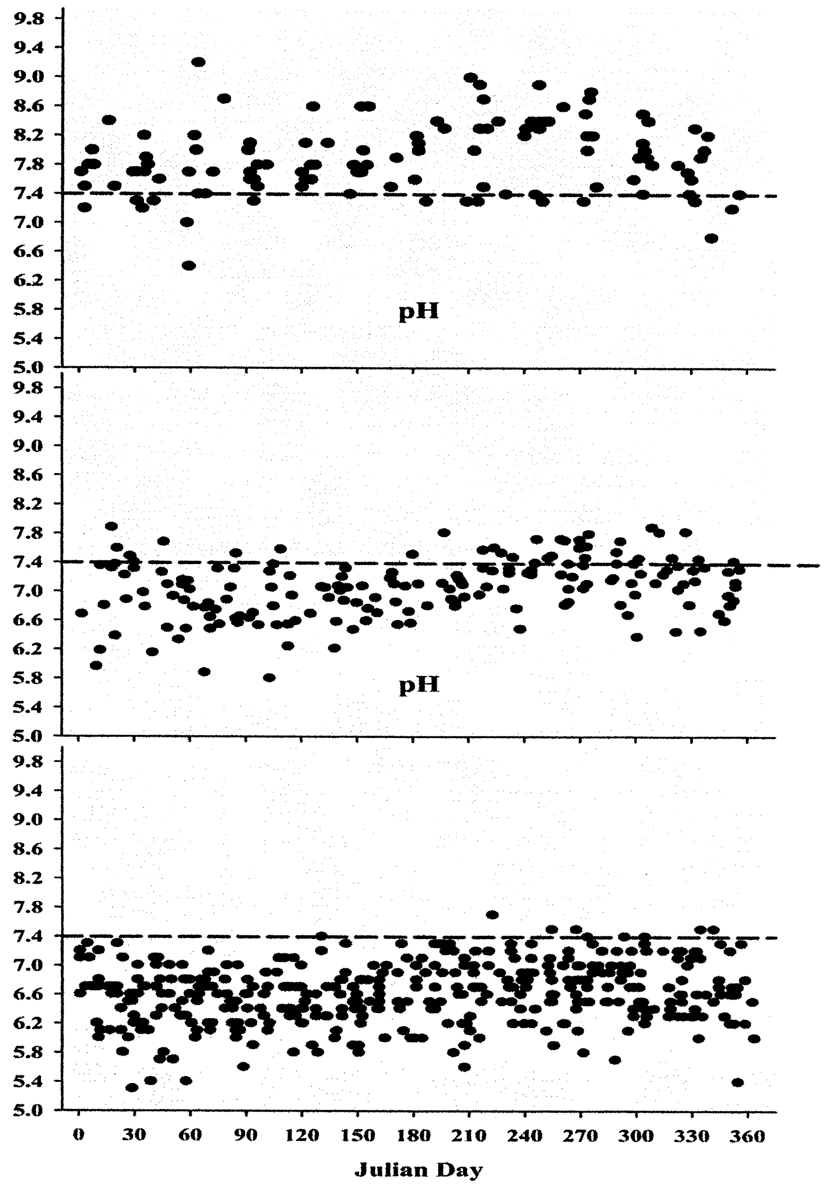

Figure 5: Summary of pH values characterizing the Arkansas River (upper plot), Bayou Bartholomew (middle plot), and the Ouachita River (lower plot). The dashed line represents the limit below which zebra mussel larvae cannot survive.

2.5. LESSONS LEARNED FROM EXAMPLE #1

Analyses of habitat conditions and physiological tolerances led to three conclusions. First, the Arkansas River near upper Bayou Bartholomew (at the location of the proposed pumping station) provided good zebra mussel habitat with respect to pH, calcium, and dissolved oxygen. However, high summer water temperatures were such that only in cool years can zebra mussels flourish in the Arkansas River [2; 3; 4]. Second, Bayou Bartholomew provides poor habitat with respect to pH and calcium ([11] and references within). Both water temperature and dissolved oxygen were slightly more suitable, but pH and calcium will be limiting for the early life stages. Third, the Quachita River offers such poor habitat with respect to pH and calcium such that it is extraordinarily unlikely that zebra mussels could establish, much less thrive, in this river.

Thus, augmentation of low flow in Bayou Bartholomew to support irrigation withdrawals by pumping of Arkansas River water is unlikely to result in colonization of the Bayou by zebra mussels. Certainly conditions for larval survival will be so poor that populations of zebra mussels are highly unlikely to be sustained in Bayou Bartholomew. Conditions in the Ouachita River, into which Bayou Bartholomew drains, are even more limiting. This particular invasive species concern should not be a major factor in environmental decision making related to this project.

3. Example #2: Retrospective Analysis of an Endangered Species Translocation

3.1. BACKGROUND

During September-October, 2002 we collected and moved more than 2,000 endangered fat pocketbook pearly mussels, *Potamilus capax,* from an approximately 6-km reach of a drainage ditch in eastern Arkansas. This translocation was aimed at protecting mussels from planned maintenance dredging and was required by a Biological Opinion prepared by the U.S. Fish and Wildlife Service. The project did not proceed as planned; we removed only about 80% of the *P. capax*. Herein, we examine mistakes made, lessons learned, and discuss procedures that might have led to a more favorable outcome. We identified three key decisions should have been thoroughly discussed prior to initiating the work: percentage of mussels to be removed, choice of recipient sites, and number of mussels to be marked and measured. Two other issues were important: the status of *P. capax* in Arkansas, and the likelihood of future dredging needs at recipient sites. Initially we felt that decision-analysis tools, used during planning, would have facilitated a better understanding of complex issues. Although they would have encouraged better discussion, it is now apparent that communication was hampered largely by the different perspectives of participants.

Native freshwater mussels (Family: Unionidae) are considered by many aquatic biologists to be the most endangered organisms in North America [58]. In 1976 twenty-four species were listed as endangered; as of January 2006 sixty-two were endangered and eight were threatened [56]. Although they reach their greatest abundance (25 to more than $100/m^2$) and species richness (20 to 30) in medium-sized to large rivers [36; 42], they are also found in ponds, lakes, and sloughs [41]. They have a unique reproductive cycle in which the newly released larval stage must undergo a two- to three-week development period on the fins or gills of a fish; hence, successful recruitment depends upon specific hosts [20; 57]. They are sedentary suspension feeders, and aside for the development period, spend their lives partially buried in substratum. Although many reasons for their endangered status have been proposed and discussed [49; 20; 34; 7; 48; 25; 58; 40; 52] large-scale alteration of free-flowing rivers in the 19^{th} and 20^{th} centuries to accommodate navigation was a major cause [24]. Federal agencies such as the U.S. Army Corps of Engineers often relocate endangered mussels to avoid impacts [14; 17]. Projects that could require mussel translocations include bridge construction, channel realignment, dam placement, or dredging to improve navigation or water conveyance.

The fat pocketbook pearly mussel, *Potamilus capax,* was proposed for listing on 26 September 1975 (40 FR 44392-44333), and listed as Endangered on 14 June 1976 (41 FR 24062-24067). It has a smooth, shiny, thin, and extremely globose, yellow, tan, or olive-colored shell [15]. Its range since 1970 includes the St. Francis River, Arkansas; White River, Indiana; upper Mississippi River north of St. Louis; lower Wabash River, Indiana; and lower Cumberland River, Indiana [5; 55]. However, *P. capax* is most likely to be found in slack water habitats in the St. Francis drainage, Arkansas [1; 27]. Although it can occur in sandy substratum, it typically inhabits a mixture of sand, clay, silt and sticky mud [1].

Stateline Outlet Ditch originates near the Arkansas-Missouri border west of Blytheville, Arkansas. It flows south, connects to the St. Francis River and joins the Mississippi River near Mile 672, west of Tunica, Mississippi. Near the town of Marked Tree, Arkansas, the river splits into the St. Francis Floodway to the west and the lower St. Francis River to the east. The lower reach of the St. Francis River, south of Marked Tree, is isolated from the surrounding watershed by levees, the Huxtable Pumping Plant to the south, and a pair of siphons to the north (Figure 6). Siphons are primed with a mechanical pump but they contain no turbines. Fish can go downstream into the St. Francis River through the siphons but not back up against the current.

The upper one-third of the ditch was sinuous, 25 to 40 m wide, with mostly firm, silt-sand substratum. The lower two thirds was 50 to 60 m wide and straight, and substratum consisted of flocculent mud 20 to 100 cm deep which made walking extremely difficult. The surrounding area was agricultural, although a strip of land between the ditch and the levees was vegetated with herbs, vines, silver maple, and willow. We estimated total benthic surface area at 66,500 m^2 and 170,000 m^2, in the upstream and downstream reaches, respectively. During retrieval there was no measurable water flow in the ditch.

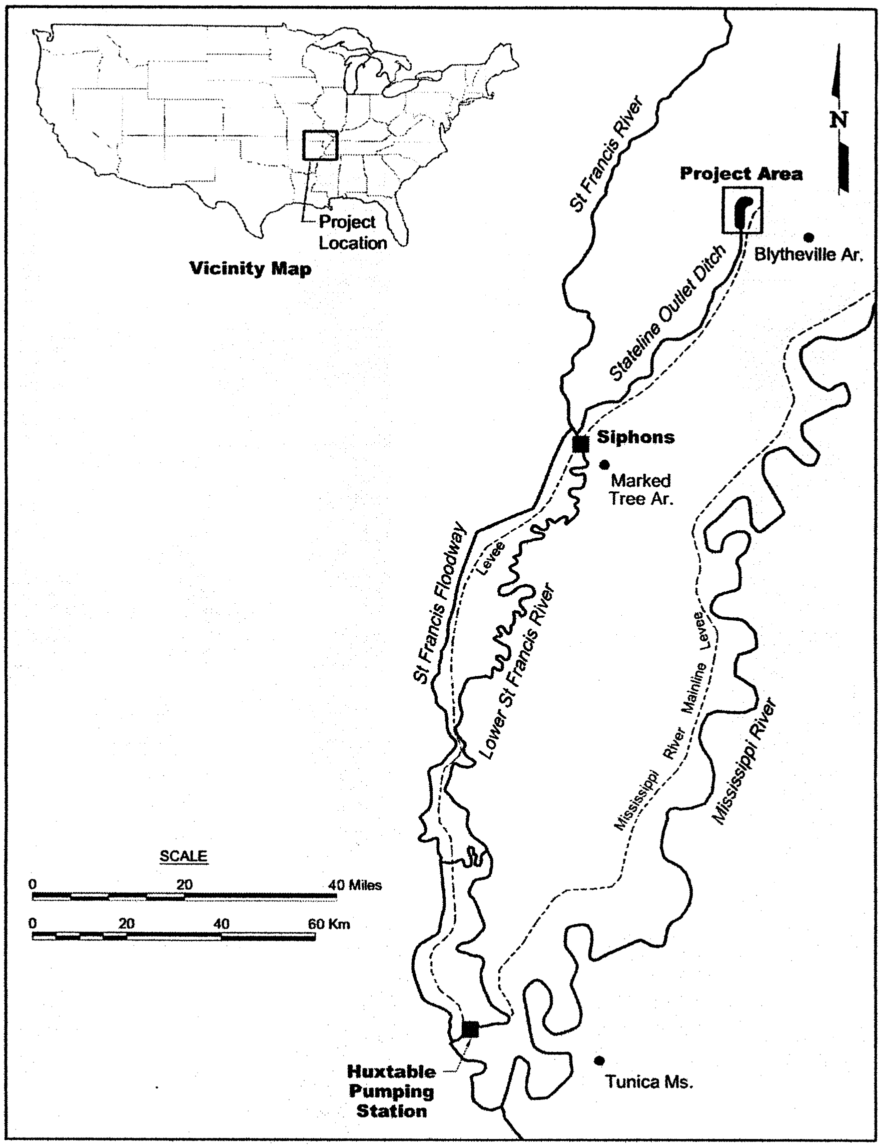

Figure 6: Location of the project area, west of Blytheville, Arkansas (left panels). Relationship of the St. Francis River, St. Francis Floodway, and levee system, located south of the project area (right panel).

3.2. IMPORTANT DECISIONS

Three important decisions affected this translocation and subsequent perceptions of its success. First was the percentage of mussels to be removed. The Biological Opinion [56] aimed at rescue of all *P. capax* in the project area, and required that all but five individuals would be moved. The Biological Opinion recognized this as potentially unrealistic, and allowed an incidental take of no more than 30 individuals that might be found in upland disposal mounds. Based on an early study [22] it was assumed that there were 3,072 *P. capax* in the project area; approximately 2,300 and 760 were in the upper and lower sections, respectively. In slight contrast to the Biological Opinion, we were asked to remove and relocate 95% (not 99%) of the mussels. Thus, although the goal of near complete removal was clear, there was ambiguity as to what could really be accomplished.

The other two important decisions concerned location of mussel recipient sites and the number that should be marked and measured. Although rationale for site selection was not discussed, presumably only those with appropriate habitat ensuring long-term survival would be suitable. The need to mark and measure mussels was related to future but unspecified growth and survival studies of translocated mussels. We were asked to mark and measure all mussels, rather than a representative subset.

There were two other important issues related to the above three questions. The first dealt with the abundance, distribution, and status of *P. capax* in Arkansas. The second concerned the likelihood of future dredging requirements at recipient sites or Stateline Outlet Ditch.

3.3. METHODS

Translocation was simple but labor intensive. Mussels were collected by wading and placed in mesh bags. They were carried to a staging area where total shell length was measured and each was engraved with an identifying number. Mussels were then packed with wet towels in coolers and transported to recipient sites and placed in substratum.

We divided the ditch into 18 reaches. Five to thirteen collectors lined up and crawled, walked, or swam, depending on water depth and the amount of mud, retrieving all live *P. capax*. Retrieval was done tactilely because of low water clarity. The area of each reach was measured and collecting time was recorded to estimate density, catch per unit effort, and depletion rate [32]. We collected mussels by hand while wading because the size of the project area (236,500 m^2) made it unreasonable to use divers equipped with scuba or surface-supplied air.

Work was not consecutive and spanned nearly two months, since collecting was restricted to low water periods. Twenty-four people participated in the 11-day project. Our inability to maintain a constant crew was partially a function of its disagreeable aspects (labor intensive, tedious, dirty, involved exposure to extremes of heat and cold, etc.). Two people left for health reasons, four commercial shell fishermen left the site with no explanation, and a commercial fisherman who had worked in other streams in this region all his life told us that this was his worst field experience.

Three relocation sites were to be used, one in a nearby ditch (# 29) and two in the St. Francis River south of Marked Tree. Ditch 29 was contiguous with the Stateline Outlet Ditch and less than 2 km away. Physical conditions in Ditch 29 (depth, water velocity, and substratum), which supported substantial numbers of *P. capax*, were virtually identical to those in Stateline Outlet Ditch. Sites on the St.

Francis River were 120 km from the project area. River flow was moderate and substratum consisted of coarse sand and silt.

3.4. LESSONS LEARNED FROM EXAMPLE #2

We had conducted a pilot test of retrieval methods in the upper reach of the ditch where an earlier study [22] indicated that most *P. capax* would be found. Results suggested that translocation was feasible and we made an estimate of the time required to remove all *P. capax*. Unfortunately, these results were misleading, since the larger and muddier lower reach was not included in the pilot study. We made a major error by not conducting more thorough test removals at various locations throughout the project area. Sufficient preliminary work should have been done to determine that the majority of the mussels were in the downstream reach and that 95% removal might not be possible. This would have provided a clearer picture of the magnitude of this translocation.

If we had examined the downstream reach in detail we would have concluded that most of the *P. capax* were located there, and they would be very difficult to remove because of deep mud. Ultimately we worked downstream reaches repeatedly without fully depleting the population. For example, in the first three passes along Reach 13 we collected 155, 39, and then 55 *P. capax*. The fact that more mussels were taken in the third versus the second pass illustrates the problem. We finally removed nearly 500 mussels from Reach 13, taking 18 on the final pass. We reworked the upper, sandier reaches three to four times and probably retrieved most *P. capax*.

We removed more than 2,000 live *P. capax* from Stateline Outlet Ditch, with the majority (78%) taken from the downstream, most-difficult-to-sample reaches. Using the depletion method of Lockwood and Schneider [32] we estimated that between 2,165 and 2,680 *P. capax* were in the project area. Therefore, we removed and relocated between 94 and 76% of the population. Translocation was stopped when it became increasingly clear that we were having difficulty removing all mussels. The following is an assessment of mistakes made and lessons learned.

We did not participate in project planning and therefore were unaware of many project details and past discussion of issues. If we had been more knowledgeable on rationale for various plans we might have been able to influence some of the decisions. A case in point is the dredging plan for Stateline Outlet Ditch, which will be discussed in more detail in the next section. We became aware of and reviewed that document after the project had been completed.

All participants (USFWS and the Memphis District) were aware of publications describing the ecology and distribution of *P. capax* [5; 10; 27; 22], the recovery plan [56], and details of previous mussel translocations [14]. Despite the fact that that everyone was aware of this literature, our restrospective analysis suggested different perspectives on four key issues. These are discussed below, with comments on how they affected decision-making and project design.

3.5. WHAT PERCENTAGE OF THE LOCAL POPULATION SHOULD BE MOVED?

In the Biological Opinion [56] it was stated that dredging would have direct and indirect effects on *P. capax*. Mussels removed by the dredge would be killed, and increased 'siltation associated with the work,' would have a deleterious effect on all others. These secondary effects would be severe enough to warrant complete (or near complete) removal.

We recently analyzed archived project specifications to determine extent of proposed dredging. Results of a hydrographic survey had been used to divide the project area into 142 sections, each 30 m (100 ft) long. Based on dredging requirements, we grouped these sections into five reaches. Half the channel in the first reach, and a 3-m strip along one bank would be affected in two downstream reaches. Two upper reaches would be completely dredged. Thus, only 50% of the project area would be affected, with less than 10% taking place in downstream reaches. The proposed action would directly affect less than 50% of the mussels, since most were in the area that was impacted least.

In the Biological Opinion [56] the recovery plan was cited [55] which stated that dredging was particularly destructive to *P. capax*. Studies by Ellis [19], Kat [28], and Brim Box and Mossa [9], were cited to bolster this statement; however, these were of mussels in general and not *P. capax* specifically. The preference of *P. capax* for sticky mud [1] suggests that this species is likely to be more tolerant of suspended sediment than species found primarily in coarse-grained substratum. Especially in reaches where only one bank was to be affected, our recommendation would have been to move mussels to the other side of the ditch. We would have suggested complete mussel removal only in two reaches that would be totally dredged.

The question of how many *P. capax* to move could have been based on genetic diversity of the population. The proportion of diversity that remains from one generation to the next is equal to $1-(1/2\ N_e)$ (N_e is the effective reproductive population) [35]. Therefore, a population of 1,000 individuals could lose 0.05%, and a population of 50 individuals could lose 1% of their diversity each year. The need to maintain genetic diversity within this population could have been addressed by estimating population size and then impacts of several removal scenarios. Since we removed approximately 2,000, the difference between total removal and 95% removal was 100 individuals, and the difference between total removal and 80% removal was 400 individuals. There must be many tens of thousands of *P. capax* in the ditches, streams, and bayous in the drainage. It is unlikely that genetic viability of *P. capax* in the drainage would be affected by these small differences.

3.6. SUITABILITY OF RELOCATION SITES

We were to use three relocation sites, one in Ditch 29, which was similar to Stateline Outlet Ditch, and two in the St. Francis River, which had silty sand substratum. We felt that *P. capax* should only be relocated in appropriate sticky mud substratum [1]. Therefore, we did not consider sites on the St. Francis River to be particularly appropriate, unless there was some overriding reason that made

Ditch 29 less desirable. Although it was not stated directly, it is likely that "range expansion" was one reason for recommending sites in St. Francis River. Although this species was already found there, moving substantial numbers to this larger area may have been perceived as having an overall benefit. Section 2.3 of the Recovery plan [55] described an attempt to augment an apparent population of *P. capax* in the Mississippi River in Missouri. Regardless of the rationale for moving *P. capax*, the prime consideration for site selection should have been chances for its long-term survival. Aside from physical conditions of habitat, the major concern should be likelihood of future developments, which would certainly require dredging. If the recipient site were dredged, *P. capax* would have to be moved a second time.

As noted above, we were unaware at the onset that the entire project area was not to be dredged. Considering the resilience of P. capax to sedimentation, we would have suggested relocating them within the project area, or slightly up or downstream of project boundaries.

These different perspectives on habitat preferences and range expansion could have been clarified during early planning with a decision tree [12] that portrayed alternatives, uncertainties, and consequences of site selection (Figure 7). Solid circles represent probability nodes which depict possible outcomes of choosing either Ditch 29 or the St. Francis River. These probabilities must add up to 100% for branches within a node and should be established beforehand. For example, if it was determined that probability of future developments requiring dredging in Ditch 29 was 80%, then the probability of not dredging must be 20%. We did not have estimates of dredging needs; however, they could have been obtained from Memphis District planners to guide site selection. Although not portrayed in Figure 7, it is likely that there would be a greater need to dredge Ditch 29 than St. Francis River. Because habitat conditions were most suitable in Ditch 29, we assess the likelihood of long-term survival in the St. Francis River as low with future developments and moderate with no future developments (Figure 7). We felt that the chances of long-time survival (future recruitment was not considered) in Ditch 29 would be moderate and high, with and without future developments.

A second consequence of site selection, range expansion, would not be accomplished (none) at Ditch 29 or in St. Francis River since *P. capax* naturally occurs there, although in low numbers. Actually, since the river is isolated from the remainder of the drainage, this alternative has no effect on overall range. Jenkinson and Ahlstedt [27] indicated that fish host for *P. capax* do not regularly go through the siphons. It is likely that the USFWS was unaware of this problem. Figure 7 illustrates how decision analysis could have been used. Portraying decisions and their consequences would have clarified issues and enhanced the likelihood of consensus, even if there was uncertainty associated with quantifying uncertainties.

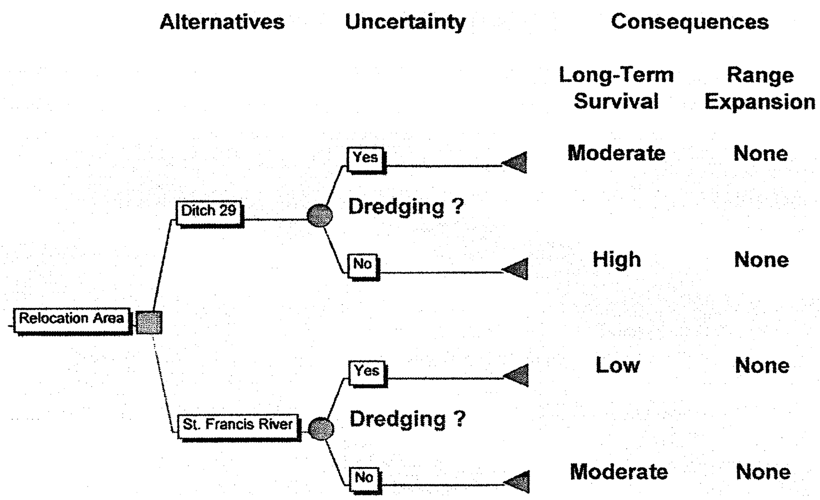

Figure 7: Decision tree illustrating alternatives and consequences of two translocation options.

3.7. MEASURING AND MARKING MUSSELS

Although not essential, most mussel translocations have a secondary goal of obtaining growth and survival data. This could have value for future projects, although in practice results can be confounded by predation, natural emigration, unexplainable mortality, and difficulty in finding translocated organisms [14]. It might seem logical to mark and measure all mussels since they had to be collected and transported anyway. However, potential logistical problems associated with holding and processing 2,000 organisms that each can weigh 300-350 grams are not trivial, especially when they are endangered, must be kept moist, and have to be carried through deep mud. Likewise there was no reason to process the entire collection; a subset of 100-200 should represent all size classes and be sufficient to estimate mortality. Finally, a sample obtained by hand-searching mud overlain by turbid water will be biased toward large organisms and length frequency histograms would underestimate recent recruitment. Unbiased samples for demographic analysis are best obtained by collecting and sieving sediments, which was done previously by Harris [22].

Using a decision tree, we judged the first three consequences of the chosen treatment scenario to vary from moderate (measure all) to low (measure a subset) to none (measure none) (Figure 8). We judged the value of measuring all or a subset as moderate, since sufficient mussels could be easily collected to obtain these data as part of another study. Regardless, it is unclear how resulting demographic or survival data would substantially contribute to the long-term success of this species. Figure 8 applies to *P. capax* and probably to most endangered species. The question for managers is simple; do the increased chances of mortality justify the need to collect such data?

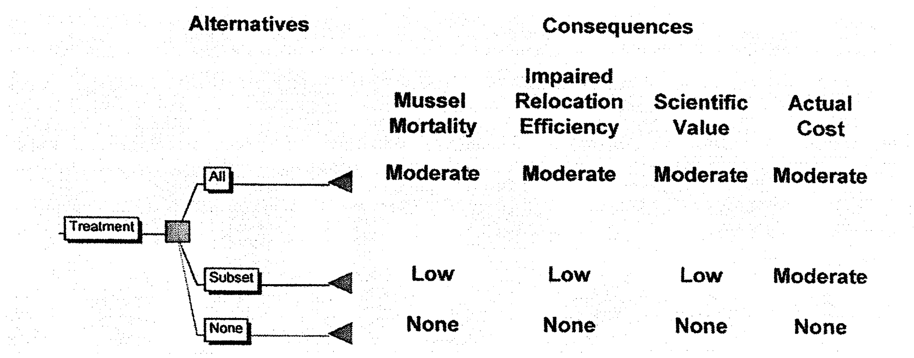

Figure 8: Decision tree illustrating alternatives and consequences of three marking and measuring options.

3.8. SHOULD *P. CAPAX* BE ENDANGERED?

Bates and Dennis [5] conducted a survey in the St. Francis drainage and reported that this species was rare and would likely soon become extinct. However, in a later, more thorough study in the same area, Clarke [10] found many hundreds and concluded that the species was not rare or spatially restricted, but common. Findings by Clarke were substantiated by subsequent investigators [1; 27]. In a review of mussels in Arkansas, Harris et al. [23] recommended that the *P. capax* be down-listed to threatened. We found several thousand *P. capax* in a 5.7 km reach of Stateline Outlet Ditch; it ranked second in abundance of 19 unionid species and comprised 20% of the fauna. The rationale for listing this species now seems questionable [37].

3.9. CONCLUSIONS FROM EXAMPLE #2

Procedural difficulties of mussel translocations to avoid impacts have been discussed by Cope and Waller [14], Losos et al. [31], Griffith et al. [21], and Parmalee and Bogan [41]. In their review of 37 projects, Cope and Waller [14] estimated that approximately 22,000 mussels died following translocations, which was likely an underestimate since mortality was reported in only 68% of the cases. Some investigators reported mortality as high as 90%. These findings alone, even if the experiences of Stateline Ditch are ignored, suggest that better assessment of risks associated with moving mussels is needed.

This retrospective analysis caused us to examine logistic problems that hindered our ability to meet project objectives. The simple decision trees developed in this retrospective analysis demonstrate how formal decision tools would have produced a better design by more clearly portraying consequences and choices. This would have focused attention on key issues, fostered better communication, and led to a common understanding of key issues. The concept of interagency cooperation through consultation is not a recent development, and was well-defined in the early 1970s [6]. It is not unreasonable to involve participants in a comprehensive decision process at the onset of an important project [8].

Difficulty in framing or making decisions was not due to incomplete information; everything needed to plan the project and assess the status of *P. capax* was available. Different perspectives obstructed meaningful communication and led to a plan that lacked foresight and was prone to errors. A major goal of the ESA is to protect ecosystems, not organisms [16; 18]. Our experiences in Stateline Outlet Ditch led us to conclude that this translocation protected neither very well. The culprit was different perspectives--which led to different conclusions--one of several reasons why decisions are hard and decision tools are useful [12].

4. Concluding Remarks

Invasive and endangered species issues, albeit central to many ecosystem management programs, are only two examples of non-toxicological problems to which risk analysis and decision methods can be applied. The two examples presented herein indicate the potential for improving environmental decision-making in the face of uncertainty - but in the presence of substantial information. As more rigorous attempts are made to widen and improve applications of risk and decision methods to environmental decision-making, the following aspects of ecosystem management are likely to be improved:

- *More systematic structuring of the decision process.* If decision makers are helped to think systematically about a problem and provided a logical framework for defining choices, better decisions are likely to result.
- *Straightforward portrayal of the consequences of decision option.* Managers and stakeholders will be better able to reach a common understanding of the relative advantages and disadvantages of management options.
- *More consistent and rational evaluations of risks and uncertainties.* This is important because behavioral and social sciences research suggest that people are inconsistent and challenged in make decisions involving risk and uncertainty – paralysis of a decision process typically will not promote better environmental management.
- *Better documentation of how a decision was reached and improved conflict resolution.* Common understanding of a complex issue and clarity of communication are made more possible as systematic approaches are taken to risk analysis and decision processes. Choices will be more defensible to various stakeholders and other interested parties.

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